Fast Diagnostic for Electrical Breakdowns in Vacuum

Timothy L. Houck
(925) 423-7905
houck1@llnl.gov

An important area of pulsed-power R&D is high-voltage vacuum insulator breakdown, often referred to as flashover due to the sudden avalanche of electrons across the insulator surface. This phenomenon is often the limiting factor in attaining the highest possible performance in pulsed-power devices. While several hypotheses attempt to explain the initiating mechanism(s), flashover is not well understood. Computational modeling is limited to establishing the electromagnetic field and radiation imposed on the insulator. The designer then makes adjustments to the configuration and/or materials until the modeling results are within safety margins based on empirical data. This design approach is believed to be overly conservative since the bulk dielectric strength of the insulating material can be an order of magnitude greater than the flashover limitation. However, without a quantitative understanding of the phenomenon this is the only approach to ensure reliability.

A major obstacle to gaining a quantitative understanding of insulator flashover is the time scale for the phenomenon. Typical vacuum electrode spacing is dependent on voltage standoff expectations with spacings on the order of a centimeter experiencing flashover in a fraction of a nanosecond. To record such flashover we require diagnostics with response times on the order of a few hundred picoseconds or faster. Equally important, the diagnostic must be compatible with the geometry of the experiment. In most applications and test stands, the insulator is located between parallel electrodes a few centimeters to tens of centimeters in transverse dimension and separated by distances of a few millimeters to a few centimeters. Diagnostics that are located away from the electrode gap, *e.g.*, on the power feeds, record a signal delayed and distorted by the intervening inductance and capacitance. These inductances and capacitances are normally very small, but for the extremely fast signals associated with flashover they act as filters that remove critical spectral components of the signal.

The goal of this project is to provide an appropriate diagnostic.

Project Goals

The deliverable for this project is a compact, high-bandwidth diagnostic that can measure the electric field in the immediate vicinity of an insulator flashover with a temporal resolution capable of capturing the initiating mechanism. In addition, the design methodology for the diagnostic is to be evaluated and documented so that similar diagnostics can be fabricated for other projects. There are presently multiple experiments and proposals directed toward the understanding of vacuum insulator breakdown/flashover. All of these studies require a fast diagnostic to record the initial buildup of the electron avalanche.

Relevance to LLNL Mission

This project provides LLNL with a more capable diagnostic for pulsed power R&D, specifically vacuum insulator studies. Our diagnostic can be included in the suite of diagnostics used for monitoring the performance of new hardware under extreme conditions, *e.g.*, explosively driven flux generators.

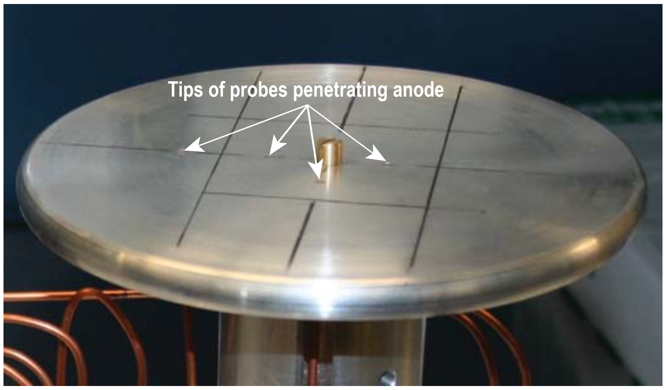

Figure 1. Anode plate with capacitively coupled diagnostic probes installed. Lines on the anode indicate the footprint of the test insulator. All but one probe are positioned under the insulator during testing.

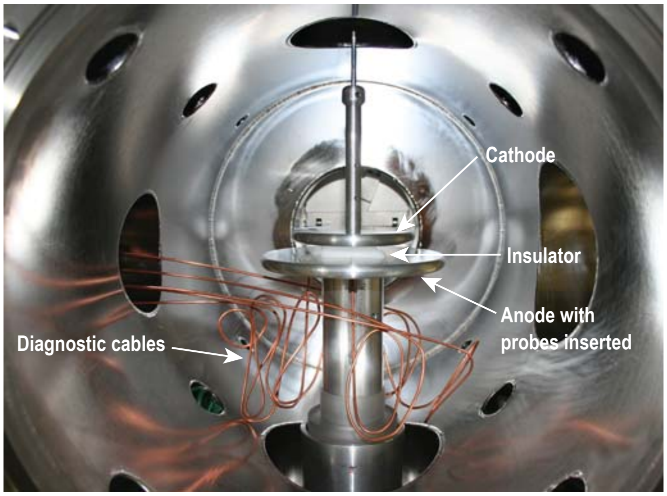

Figure 2. Electrodes positioned in vacuum test chamber.

At a more basic level, this fast diagnostic is a tool for understanding flashover and benefits projects studying flashover in general. If the information acquired by this diagnostic leads to a fundamental understanding of flashover, all high power, pulsed power systems would be impacted. These systems include high-current particle-beam accelerators, high-power radio frequency and microwave sources, high-power laser sources, pulsed neutron sources, nuclear weapons effects simulators, lightning and electromagnetic pulse effects simulators, x-ray and proton radiography machines, inertial fusion drivers, directed energy weapons, and electromagnetic launchers.

FY2007 Accomplishments and Results

Diagnostic probes were fabricated and demonstrated involving insulator flashover testing. Several steps were involved in the successful fielding of the probes:

1. A general design based on a D-dot probe for measuring the time rate of change of the electric field was chosen, based on measurement quantity and physical size constraints.
2. A survey of commercially available components was undertaken.
3. Electrostatic simulations were performed to calculate the probe's response and estimate its sensitivity and potential bandwidth.
4. A prototype was fabricated and tested/calibrated.
5. Five probes were installed in the anode of an insulator test chamber (Figs. 1 and 2).

The frequency response of the probe was computationally estimated to be in excess of 100 GHz. Figure 3 is a sample probe signal. The response of the probes exceeds commercially available digitizing capability. The two traces correspond to a flashover on the insulator surface immediately above the probe and a breakdown event distant from the probe. The changing electric field due to the electron avalanche is noted and partially resolved. The raw probe signal has been converted to diode voltage in Fig. 4. The conversion parameters used were calculated from simulations and agreed well with the known charge voltage.

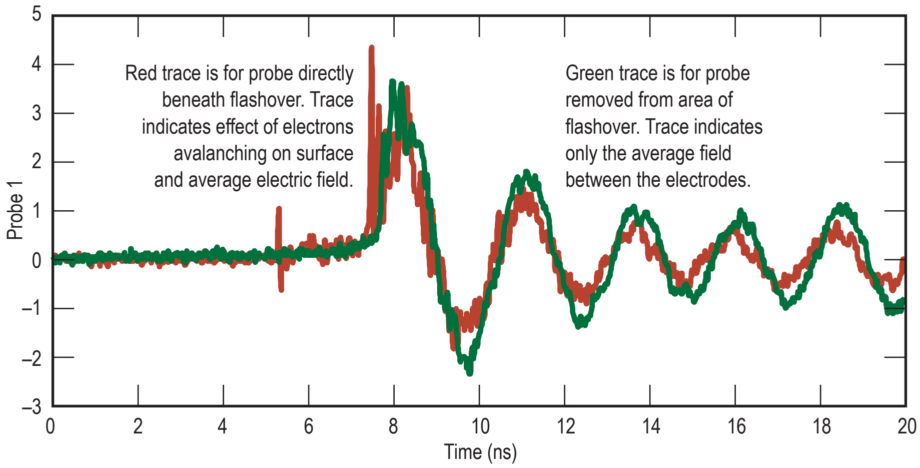

Figure 3. Raw signal from fast diagnostic probe. The signal is proportional to the electric field on the surface of the inner conductor of the probe.

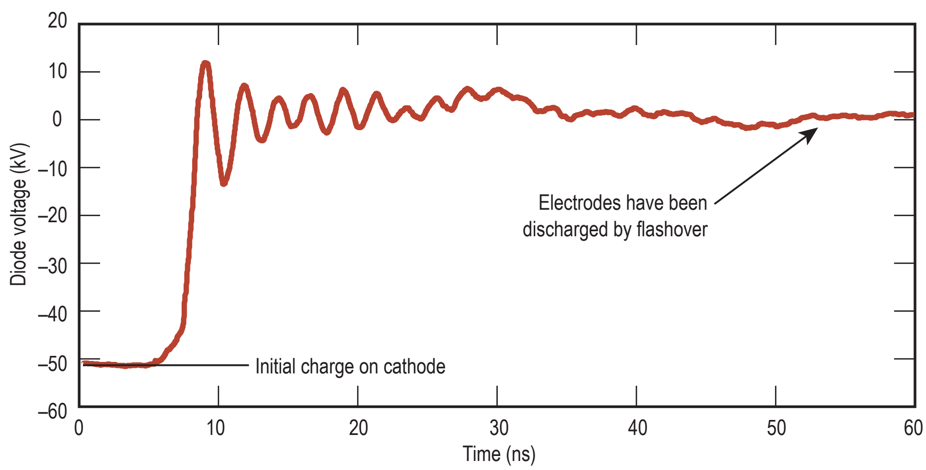

Figure 4. The raw probe signal, converted to show the potential difference between the electrodes with the cathode at -52.5 kV prior to discharge.

Related References

1. Humphries, S. Jr., Principles of Charged Particle Acceleration, John Wiley and Sons, New York, 1999, Chapter 9.14.
2. Wetzer, J. M., "Vacuum Insulator Flashover: Mechanisms, Diagnostics and Design Implications," *Proc. XVIIth International Symposium on Discharges and Electrical Insulation in Vacuum,* Berkeley, California, pp. 449-458, 1996.
3. Enloe, C. L., and R. M. Gilgenbach, "Microscopic and Macroscopic Material Property Effects on Ultraviolet-Laser-Induced Flashover of Angled Insulators in Vacuum," *IEEE Trans. Plasma Sci.*, **16,** 3, pp. 379-389, June 1988.

FY2008 Proposed Work

With our confidence in the success of this project, we will explore placing probes in Flux Compression Generators. Further R&D related to the application of the probes is expected to be associated with techniques for processing/analyzing the output signals to take advantage of the large bandwidth.